Why does coffee spill?

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Group meeting

Ig® Nobel Prizes

The Ig Nobel Prizes honor achievements that first make people **laugh**, and then make them **think**. The prizes are intended to celebrate the unusual, honor the imaginative — and spur people's interest in science, medicine, and technology.

2012 PHYSICS PRIZE: Joseph Keller et. al, for calculating the balance of forces that shape and move the hair in a human ponytail.

2010 PHYSICS PRIZE: Lianne Parkin et. al, for demonstrating that, on icy footpaths in wintertime, people slip and fall less often if they wear socks on the outside of their shoes.

2008 PHYSICS PRIZE. Dorian Raymer et. Al, (UCSD) for proving mathematically that heaps of string or hair or almost anything else will inevitably tangle themselves up in knots.

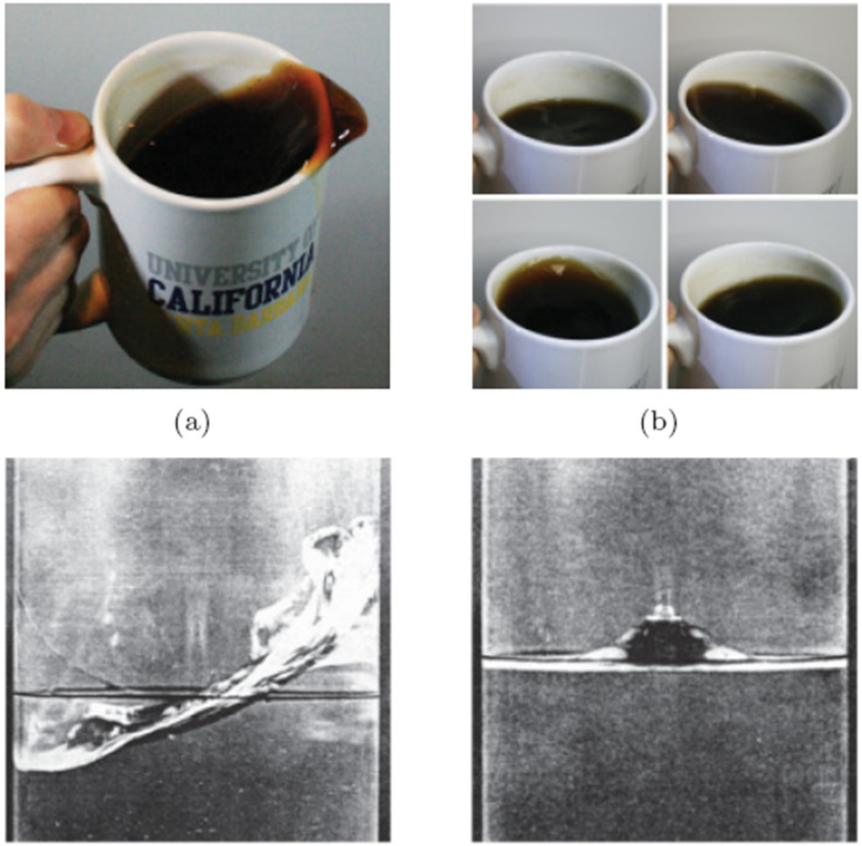
2006 PHYSICS PRIZE: Basile Audoly et. al, for their insights into why, when you bend dry spaghetti, it often breaks into more than two pieces.

2003 PHYSICS PRIZE: Jack Harvey et. al ,for their irresistible report "An Analysis of the Forces Required to Drag Sheep over Various Surfaces."

- **2012 FLUID DYNAMICS PRIZE**: Rouslan Krechetnikov [USA, RUSSIA, CANADA] and Hans Mayer [USA] for studying the dynamics of liquid-sloshing, to learn what happens when a person walks while carrying a cup of coffee.
- REFERENCE: "Walking With Coffee: Why Does It Spill?" Hans C. Mayer and Rouslan Krechetnikov, Physical Review E, vol. 85, 2012.

When and why coffee spills?

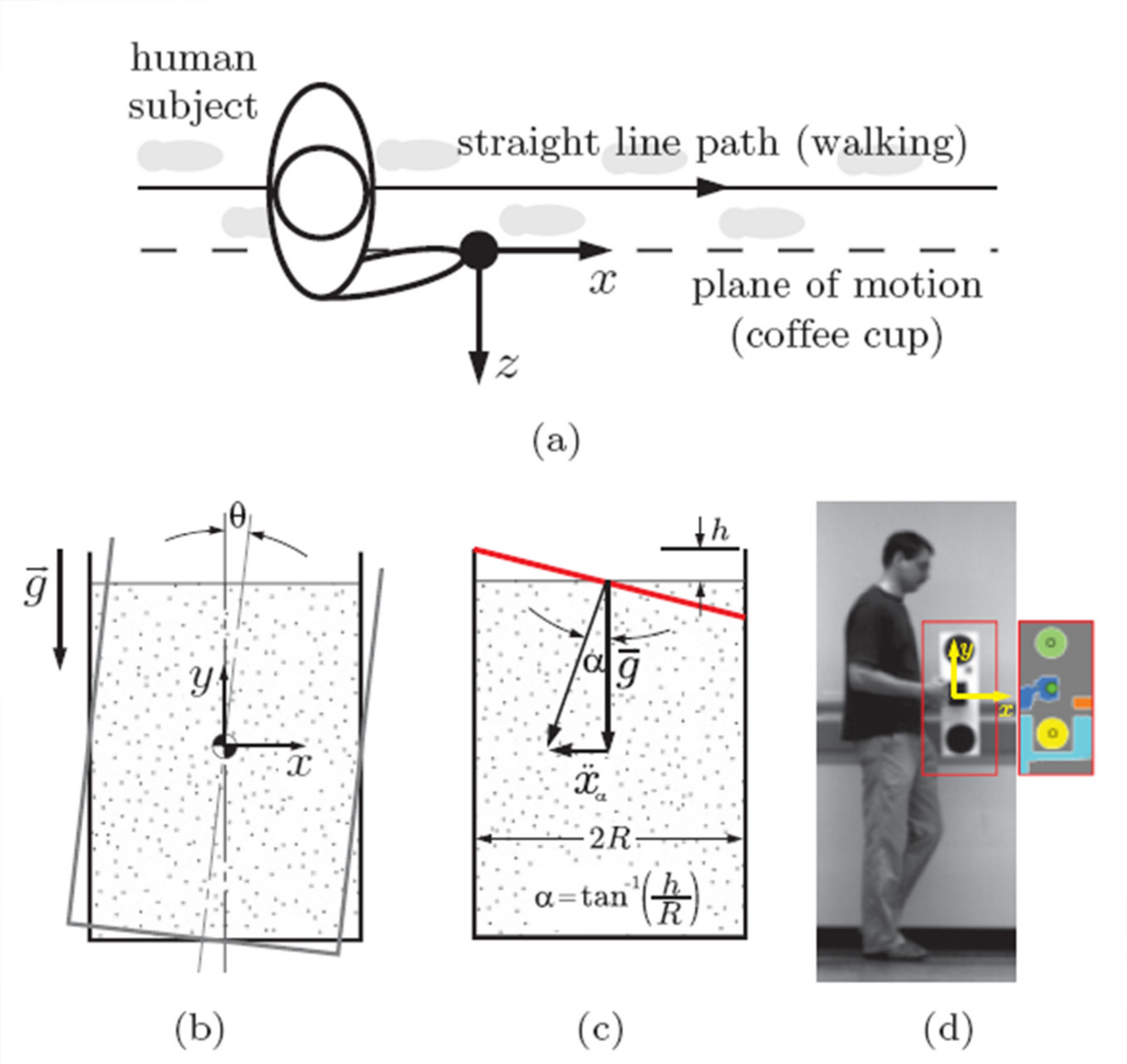
- Bio-mechanics of human walking
- Liquid sloshing engineering



(a) (b)

(c) (d)

Definition and coordinates in the coffee spill experiments



- Focused
- Unfocused
- LED indicator

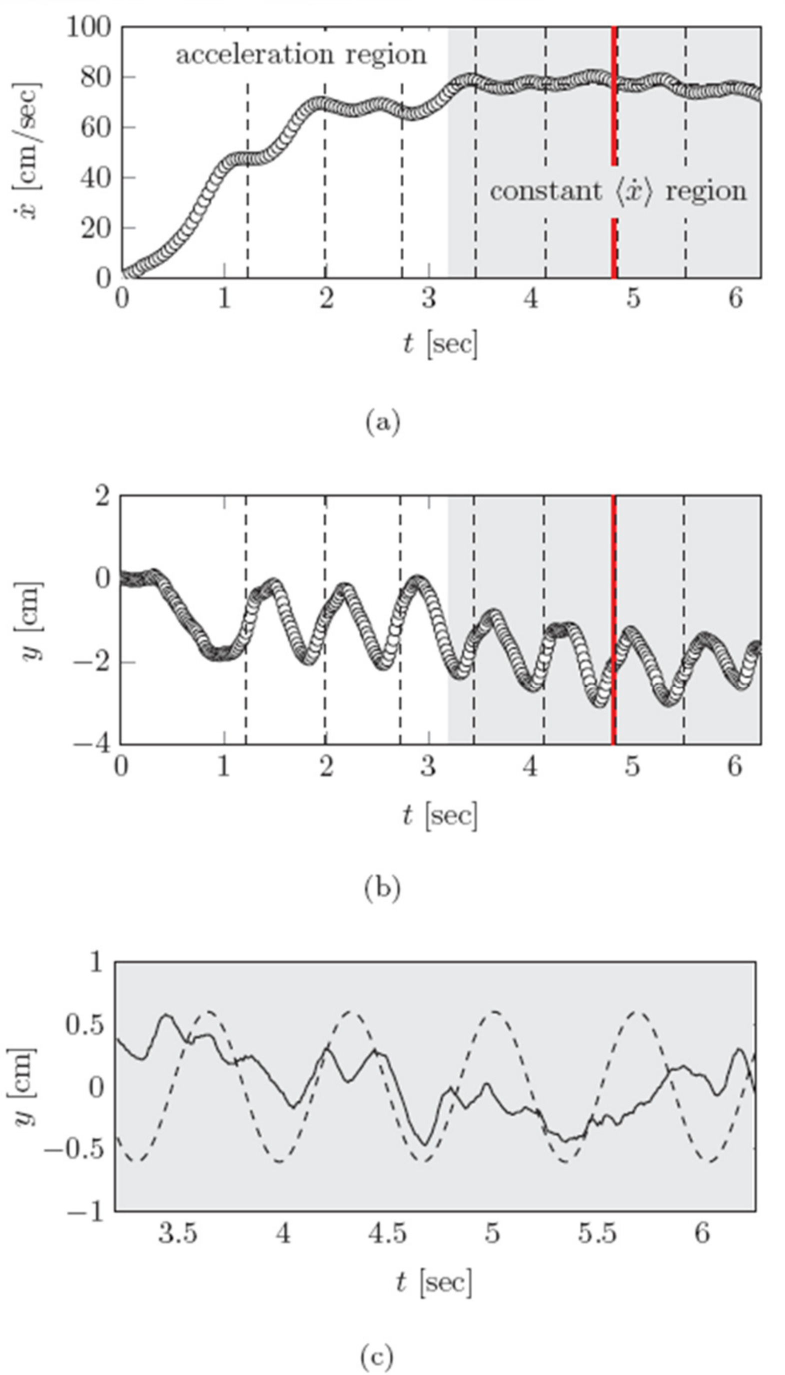
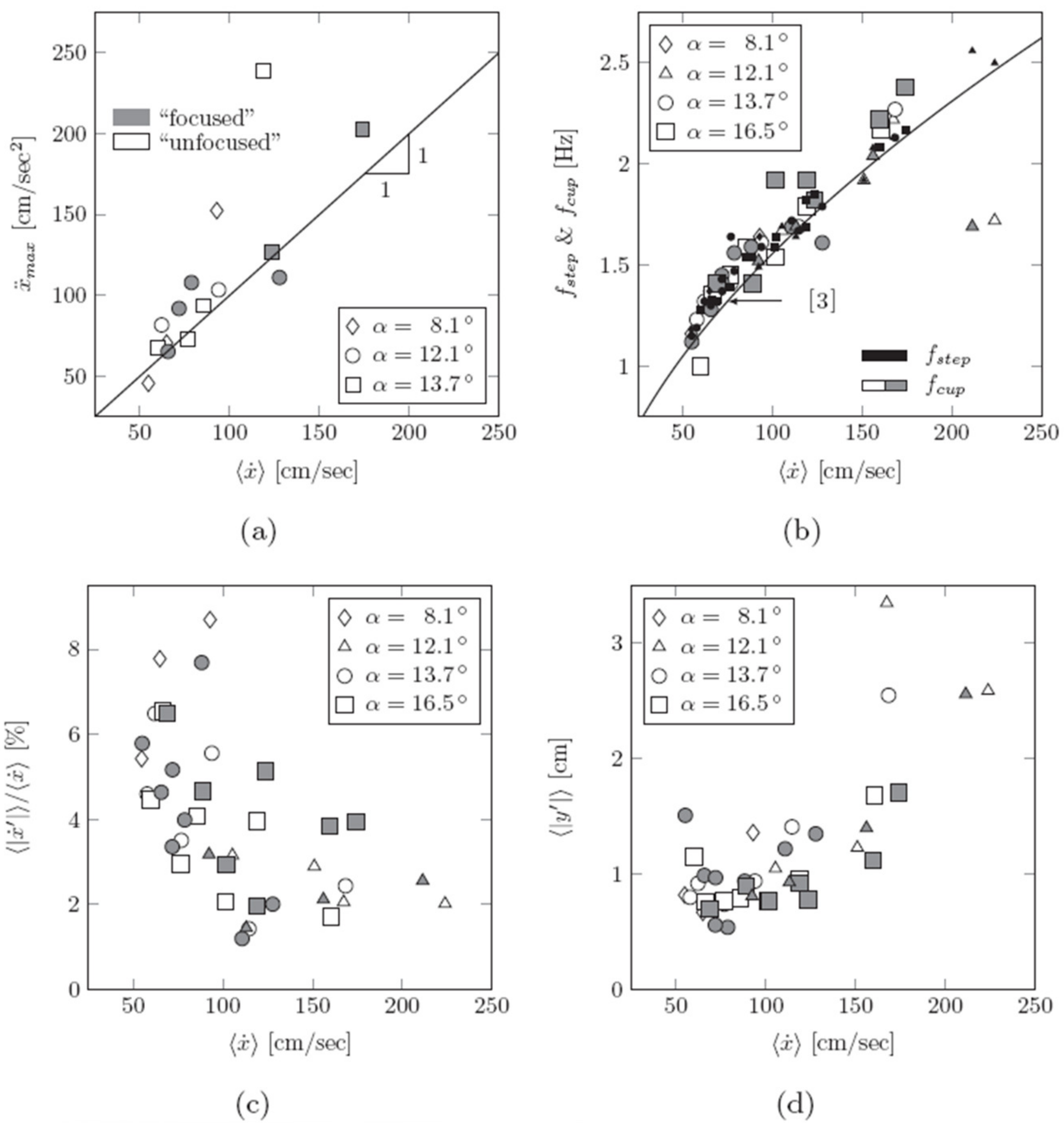


FIG. 3. (Color online) The trajectory of the coffee cup determined from image analysis for (a) back-and-forth and (b) vertical excitation. (c) The decomposition of the signal shown in the shaded region in (b) into smooth (dashed line) and noise (solid line) components. (a)–(c) depict cup excitations in the unfocused regime with walking speed $\langle \dot{x} \rangle = 80$ cm/s, maximum acceleration 71 cm/s, and coffee level $\alpha = 12.1°$; shaded region corresponds to the regime of constant average velocity, the red (solid vertical) line shows the instant of the first coffee spill, and the dashed vertical lines correspond to step instants.



a) $v \uparrow \rightarrow a_{max} \uparrow$

$a_{focused} < a_{unfocused}$

b) $f_{cup} \approx f_{step}$

f_{cup} = 1~2.5 Hz

c) the faster one walks, the smoother the motion of the cup in the x direction,

d) Walking faster results more up and down movements.

Why spills? v_{nat} vs. f_{cup}

The natural frequencies of oscillations of a frictionless, vorticity-free, and incompressible liquid in an upright cylindrical container (cup) with a free liquid surface are well known from liquid sloshing engineering

$$\omega_{mn}^2 = \frac{g\,\epsilon_{mn}}{R}\tanh\left(\epsilon_{mn}\frac{H}{R}\right)\left[1+\frac{\sigma}{\rho g}\left(\frac{\epsilon_{mn}}{R}\right)^2\right]$$

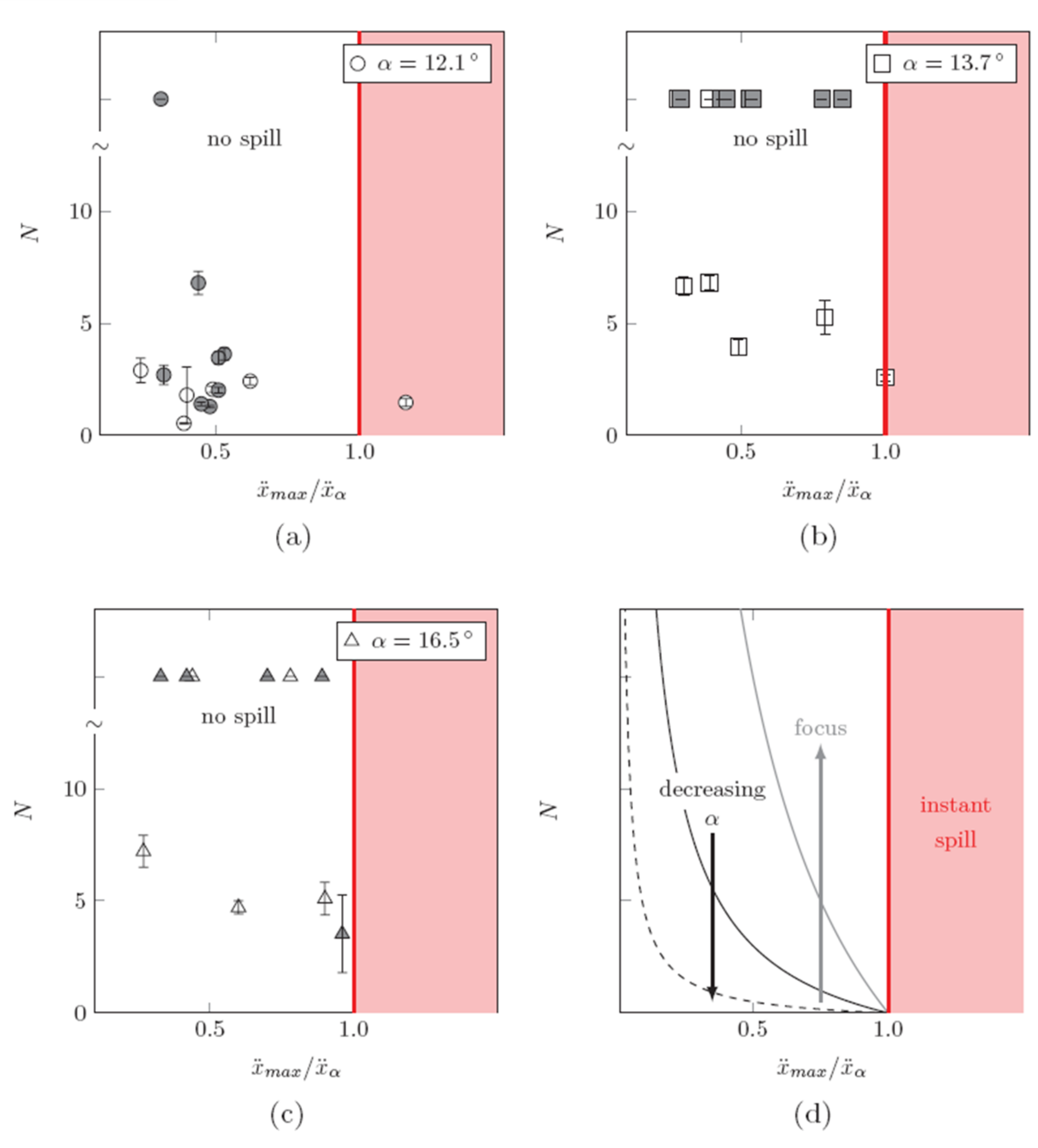
R =3.5 cm ,*H*=10 cm, the angular frequency is

$\omega_{11} = \omega_{nat} \sim 23$ rad/s, so $v_{11} = v_{nat} \sim 3.65$ Hz

natural frequencies of cups in the range 2.6~4.3 Hz

f_{cup} = 1~2.5 Hz tends to excite the lowest –frequency mode during walking, which exhibits the largest liquid mass participating in the back-and-forth sloshing and thus leads to the largest effect on the dynamics of the system.

When spills?



Time to spill generally depends on whether walking is in a focused or unfocused regime and increases with decreasing maximum acceleration (walking speed).

~4~5m(7~10 steps)

Suggested strategies to control spilling

- Start your walk slowly
- watch your mug
- Don't fill your mug too high
- Container design:

(a)using a flexible container to act as a sloshing absorber in suppressing liquid oscillations

(b) using a series of concentric rings (baffles) arranged around the inner wall of a container to damp the oscillations.

(c) draw a fill line inside the mug

Thank you!